P1.7 Sensible heat flux estimates using AVHRR and scintilllometer data over grass and mesquite in Northwest Mexico

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Introduction

One of the challenges in using remote sensing for energy budget estimation is to retrieve accurate values of sensible heat fluxes. Actually this problem requires solving other issues: first, retrieving accurate estimates of soil surface temperature from satellite data (and to be able to extrapolate them temporally) and second relating estimates of the sensible heat flux obtained over relatively large surfaces from satellite data (1 km^2 to 16 km^2) to ground measurements usually representative of less than 0.1 km^2. In this study, we will confine our attention to the estimation of the instantaneous sensible heat flux over semiarid areas using AVHRR data. Once accurate (±1ºC) estimates of surface temperature are obtained, a way of estimating the transfer coefficient and a means of validating the resultant estimates of the heat flux will be presented. This point is addressed using a large aperture scintillometer which gives path-integrated measurements of sensible heat flux over distances of up to 5 km.

Data

The study was performed in the framework of the SALSA programme (Goodrich et al., 1998). The sites are located in Mexico close to the town of Canaea in NW Sonora and some 40 km from the US border. The area is semiarid with a vegetation layer consisting of grass and mesquite bushes. Data collected on the ground included vegetation characteristics (type, density, LAI), soil moisture (surface and profiles), surface and air temperature, rainfall and fluxes (solar and net radiation, sensible heat, water vapor and CO_2). The grass site was also equipped with a Large Aperture Scintillometer (LAS) which provides estimates of sensible heat flux along a path between the transmitter and the receiver at a distance of 600 m, with a 6 m tower measuring fluxes in the middle. Both receiver and transmitter were located 2.65 m above the surface.

Satellite data is full resolution (1 km) AVHRR data acquired for afternoon passes of NOAA 14. Pre-processing consists of geolocation, with atmospheric corrections (Rayleigh, water vapor and standard values for aerosols and carbon dioxide) for the shortwave bands.

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Surface temperature retrieval

After an extensive review of the literature and analysis of the problem (Kerr et al., 1997), we have identified that, from the current state of the art and for the application in mind, we had to rely on a Split Window Technique (SWT) algorithm. Actually, the only possibility to obtain the total atmospheric water vapor content, when no synchronous (both in time and space) radio soundings are available, is to use the global fields provided by forecasting models like those archived at ECMWF or to use SWT algorithms. The problem then is to correctly estimate the emissivities. From an intensive comparison of 21 algorithms it was found that, provided we had access to surface emissivity, the most suitable was (Uliveri et al., 1994)

$$T_s = T_4 + 2.76\,(T_4 - T_5) + 38.6\,(1 - \varepsilon) - 96.0\Delta\varepsilon \qquad (1)$$

where T_s is the radiative surface temperature, T_4 and T_4 are the brightness temperatures of channels 4 and 5 of the AVHRR, ε is the mean emissivity in channels 4 and 5 while $\Delta\varepsilon$ is the difference in emissivity between channels 4 and 5.

The algorithms tested vary considerably in complexity and were usually very locally validated. So the main issue is to be able to take into account emissivity. Different methods exist to retrieve emissivity from satellite data. Not all of them are adequate for the purpose of this study. We found that an estimate of emissivity from the expression :

$$\varepsilon = \varepsilon_v P_v + \varepsilon_s\,(1\text{-}P_s) + d\varepsilon \qquad (2)$$

where P_v : vegetation cover fraction, P_s : soil cover fraction, e_v : vegetation emissivity, e_s : bare soil emissivity and $d\varepsilon$ is the errror associated with the approximation.

The vegetation cover fraction is calculated from:

$$NDVI = NDVI_v\,P_v + NDVI_s\,P_s + di \qquad (3)$$

with NVDI : pixel NDVI, $NDVI_v$: vegetation NDVI, $NDVI_s$: soil NDVI and di : the error related to the approximation. Thus emissivity can estimated from the measured NDVI and known values for emissivity and NDVI of vegetation and soil.

The vegetation cover method, due to its simple formulation, is easily applicable on the composite images. However, the drawback of this simplicity is that the method doesn't rely on any physical statement but on an a priori knowledge of emissivity. Study of error shows that a relative uncertainty on the soil emissivity of n% will induce, in the case of a sparsely vegetated area, an error of n% on the emissivity of the pixel. A good a priori knowledge is necessary to attain a good accuracy.

The results gained from the afore mentioned study (Kerr et al., 1997) allow us to conclude that the most suitable algorithm was the Uliveri et al (1992). However, when the emissivities are not known, the Kerr et al (1992) algorithm may be used, giving somewhat similar results (Vasquez et al 1997) with a simplified approach. The study also showed that the maximum errors for Uliveri's algorithm are obtained for high water vapor content and low emissivities, being around 2K (at nadir) and 2.5K (at 55°).

Satellite estimate of Sensible heat flux

The equation used to estimate the sensible heat flux H is (Chehbouni et al, 1997):

$$H = \rho c_p \, \beta (T_s - T_a) / r_a \qquad (4)$$

where T_a is air temperature and r_a is aerodynamic resistance. The factor β is introduced to account for the difference between the radiometric (T_s) and aerodynamic (T_0) surface temperature:

$$T_0 = \beta \, T_s + (1 - \beta) \, T_a \qquad (5)$$

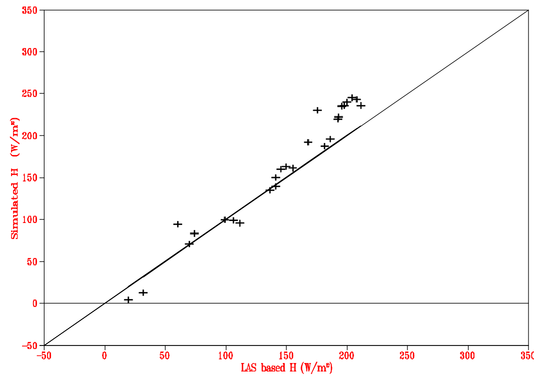
and has been shown to be a function of LAI, so it may be derived from NDVI. The resistance r_a varies with wind speed, but this variation is much reduced when stability effects are included and a constant value is usually adequate. Thus air temperature T_a is the only ancillary measurement required.

LAS estimate of sensible heat flux

The LAS measures variation in air refractive index and this can be related to the structure parameter C_{TT}, which in turn is related to H using Monin-Obukhov similarity theory (McAneney et al, 1995 ; Lagouarde et al, 1996).

The long path length of the LAS provides sensible heat flux measurements on the same spatial scale as the satellite. Furthermore, the spatial averaging means that less temporal averaging is needed to obtain stable values and realistic values can be obtained with 10 minutes averages. Thus both space and time scales are more appropriate to comparisons with (near) instantaneous satellite estimates than more traditional micrometeorological techniques, such as eddy correlation. The next figure shows a comparison between H measured by the LAS over mesquite and the use of equation 4 using ground-based surface temperature data and $\beta = 0.25$.

These results are quite satisfactory although there is evidence of bias, which might be caused by the use of surface temperature measurements which are only representative of a very small area (<1 m^2).



Conclusion

A plausible scheme for calculating sensible heat flux using AVHRR data and air temperature has been presented. We have shown that the "β method" (equation 4) gives reasonable estimates of H when used with ground based temperature measurements, while other studies indicate that the Uliveri algorithm gives estimates of T_s to better than ±2°. Therefore we might expect to obtain reasonable instantaneous estimates of H from AVHRR data, although probably with a large scatter. These data are being processed and the results will be presented at the AMS Meeting.

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